

NASA/CR-1998- 206760

FINAL
IN-91-CR

10 CIT

052346

p4

FINAL REPORT

January, 1998

NASA GRANT NAGW-3633

4/1/93 to 3/31/97

EXPERIMENTAL STUDY OF LUNAR AND SNC MAGMAS

P.I. Malcolm J Rutherford
Geological Sciences Department,
Brown University, Providence R.I.

PROJECT SUMMARY

1. General The research described in this progress report involved the study of petrological, geochemical and volcanic processes that occur on the Moon and the SNC parent body, generally accepted to be Mars. The link between these studies is that they focus on two terrestrial-type parent bodies somewhat smaller than earth, and the fact that they focus on the role of volatiles in magmatic processes and on processes of magma evolution on these planets.

The work on the lunar volcanic glasses has resulted in some exciting new discoveries over the years of this grant. We discovered small metal blebs initially in the A15 green glass, and determined the significant importance of this metal in fixing the oxidation state of the parent magma (Fogel and Rutherford, 1995). More recently, we discovered a variety of metal blebs in the A17 orange glass. Some of these Fe-Ni metal blebs were in the glass; others were in olivine phenocrysts. The importance of these metal spheres is that they fix the oxidation state of the parent magma during the eruption, and also indicate changes during the eruption (Weitz et al., 1997). They also yield important information about the composition of the gas phase present, the gas which drove the lunar fire-fountaining.

One of the more exciting and controversial findings in our research over the past year has been the possible fractionation of H from D during shock (experimental) of hornblende bearing samples (Minitti et al., 1997). This research is directed at explaining some of the low H₂O and high D/H observed in hydrous phases in the SNC meteorites.

2. Progress on specific projects

a) Picritic Lunar Glasses, Volcanism, Volatiles, and Lunar Oxidation State

Primitive picritic lunar glasses, such as the Apollo 15 green and the Apollo 17 orange glasses, are widely considered to be the products of volcanic fire-fountaining in the lunar mare (Ridley et al., 1973; Heiken et al. 1974; Meyer et al. 1975; Delano, 1979). Although the "fire-fountain theory" appears to be the most plausible explanation for the formation of primitive lunar glasses, many basic elements regarding their genesis and significance remain unknown. Among these are: 1) The volatiles present in the primitive lunar melts, 2) The composition of the evolved volcanic gas phase, 3) The amount of melt degassing, the depth at which it occurs, and its effect on the oxidation state of the glasses, 4) The physical processes involved and the timing of the different eruption phases.

Sato et al. (1973) and Sato (1976, 1979) proposed that lunar fire-fountain eruptions were driven by oxidation of reduced carbon and the subsequent degassing of C-O gasses upon magmatic ascent. The auto-reduction behavior of 74220 orange glasses was presented as evidence for the presence of reduced-C within these glasses. The distribution

of coatings found on the glass bead surfaces indicate that the coatings are condensates from a hot volcanic gas, a gas which slowed cooling of the glasses during eruption (Arndt et al., 1984; Arndt and Von Engelhardt, 1987). These deposits indicate that the volcanic gas contained S, Cl and C as well as volatile metals, but the composition and abundance of gas still remains to be determined. Research during the period of this grant has identified Fe-Ni metal spherules "exsolved" in two main volcanic glass types, the A17 orange and A15 green glasses. This metal is interpreted to have formed by a reduction reaction during the gas formation process (Rutherford and Fogel, 1995; Weitz et al., 1996). These discoveries yield new evidence about the oxidation state of these magmas at depth, the depth of the gas generation process, and they indicate new approaches we can follow to better understand the origin and eruption of the picritic magmas. We have also found chromian spinels in these olivine phenocrysts adjacent to the metal blebs (Rutherford and Wietz, 1997). The spinel-melt equilibria confirm the oxidation state estimate coming from the metal-melt considerations.

b. The KREEP-QMD-Granite association on the Moon:

A project to experimentally determine the relationships between KREEP basalt, quartz monzodiorite (QMD), and lunar granites (Holmberg and Rutherford, 1994) is complete and the manuscript is essentially written. The problems studied are the following. The lunar sample suite contains some pristine KREEP basalt samples such as those found at the Apollo 15 site, as well as those at A14 and A17. Associated with KREEP are intermediate composition (based on major elements) samples of QMD with very high REE abundances, and the lunar granites (e.g., Ryder, 1976; Jolliffe, 1991). We have worked to determine the possible petrogenetic relationships between these rocks.

We have now determined that a composition such as A15 KREEP fractionates along a path at 3 kb that is similar to the 1 atm fractionation, but the miscibility gap (SLI) also expands to higher temperatures with increasing pressure (Rutherford et al., 1996). This expansion is such that SLI develops when the SiO₂ content of the residual melt is no more than 52-53 wt % compared to 54-55 % at 1 atm. This means that lunar granites formed at depth are almost certainly produced by SLI, and that intermediate composition magmas such as QMD become more difficult to produce at depth.

c. SNC Meteorite Studies

The SNC meteorites and the role of volatiles in SNC magmatic processes is another problem we have continued to study. To review, geological evidence strongly suggests the presence of significant H₂O abundances on Mars throughout its history (e.g., Carr, 1986), and petrological studies identified kaersutitic hornblende (and rare biotite) inside melt inclusions in many of the SNC meteorites (Floran et al., 1978; Treiman, 1985; Johnson, et al., 1991;

McSween and Harvey, 1993). On the other hand, little evidence of water exists in the SNC meteorites outside of the phenocrysts; few hydrous minerals are present and the impact glasses contain only traces of H₂O. Wanke (e.g. Carr and Wanke, 1991) uses the low total H₂O of the SNC meteorites (180ppm) to argue the SNC magma came from a mantle with even less H₂O than the terrestrial mantle.

The idea of lower water contents in Mars magmas is also indicated by H and D abundances measured in SNC meteorites. Watson et al. (1994) found the water content of kaersutitic amphibole and other "hydrous" minerals in and outside the melt inclusions to be much lower than would be expected based on F and Cl abundance in these phases and on phase equilibria consideration (Johnson et al., 1991). Watson et al. (1994) also confirmed that the glass in the melt inclusions had no dissolved water. Two possible explanations exist for these observations: (1) it may be possible to grow kaersutitic hornblende (and Ti-rich biotite) from a low H₂O melt. This origin is suggested by the work of Popp et al., (1995) who found a coupled substitution of an H-poor oxycomponent with increased Ti in the hornblende. (2) Alternatively, the hornblendes in SNC melt inclusions may have contained a normal H₂O content, possibly approaching that required by a coexisting melt with 1 wt% H₂O as proposed by Johnson et al. (1991), and this H was preferentially lost during the shock metamorphism that affects all SNC meteorites. This process would result in high D/H ratios in the SNC minerals as observed by Watson et al. We have done one set of experiments to test these models and some exciting progress has been made on the shock experiments (Minitti et al., 1997).

PUBLICATIONS AND THESES

- Rutherford, M.J., and Fogel, R.A. (1993), C-O volatiles in Apollo 15 and 17 volcanic glasses, LPSC XIV, p 1223-25.
- Ford, D.F. and Rutherford, M.J., 1993, Primitive SNC parent magmas and crystallization: low PH₂O experiments. LPSC XXIV, p 503-505.
- Holmberg, B., and Rutherford, M.J., 1994, An experimental study of KREEP basalt evolution. LPSC 25, p. 557-558.
- Rutherford MJ and Fogel RA (1995) Apollo 15 Green glass volatiles and Oxidation state. LPSC 26, 1205-1206.
- Fogel, R.A. and Rutherford, MJ (1995) Magmatic volatiles in primitive lunar glasses: FTIR and EMP analyses of A15 green and yellow glasses and revision of the volatile assisted fire-fountaining theory. *Geochim Cosmochim Acta* 59: 201-215.
- Rutherford, MJ, Tonks, B and Holmberg, B, 1996, Experimental study of KREEP basalt evolution: origin of QMD and granite at the base of the lunar crust. LPSC XXVII, p 1113-4.
- Weitz, C.M., Rutherford, M.J., and Head, J.W., 1997, Composition and Textures of Impact and Volcanic Glasses in the 79001/2 Core. LPSC XXVIII, p. 1533-34.
- Weitz, C.M., Rutherford, M.J., and Head, J.W., 1997, Oxidation States and ascent history of the Apollo 17 volcanic beads as inferred from metal-glass equilibria. *Geochimica Cosmochimica Acta*, 61, p. 2765-75.
- Minitti, M., Rutherford, M.J., Gilotti, B.J., and Schultz, P.S., 1997, The effects of Impact on D/H in hornblendes: Application to SNC Petrogenesis. LPSC XXVIII, p. 959-60.
- Rutherford M.J. and Weitz, C.M., 1997, Oxidation State of the A17 orange glass source as inferred from Inclusions in olivine phenocrysts. LPSC XXVIII, p. 1211-12.